There is therefore a need to provide an electrochemical cell that overcomes or at least ameliorates, one or more of the disadvantages described above.

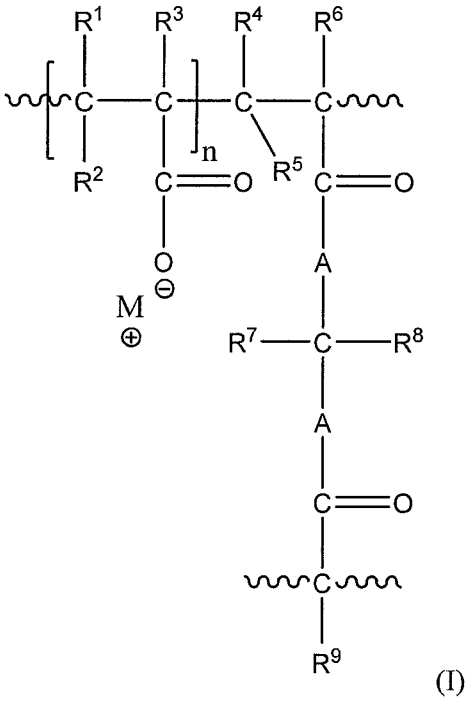
Summary

There is provided an electrochemical cell comprising:

an anode structure comprising an element selected from the group consisting of group 1, group 2, group 8, group 12 and group 13 of the Periodic Table of Elements;

a cathode structure comprising a catalyst; and

a hydrogel located between the anode structure and the cathode structure, wherein the hydrogel comprises water and a cross-linked polymer having repeating units of the following formula (I):



(I)

wherein A is selected from the group consisting of –NH-, -C(O)O-, -OC(O)-, and -C(O)NR^{10}C(O)-;

R^1, R^2, R^3, R^4, R^5, R^6, R^7, R^8,R^9 and R^{10} are independently selected from the group consisting of hydrogen, optionally substituted alkyl, optionally substituted alkenyl and optionally substituted alkenyl;

M is an alkali metal;

n is an integer of at least 1; and

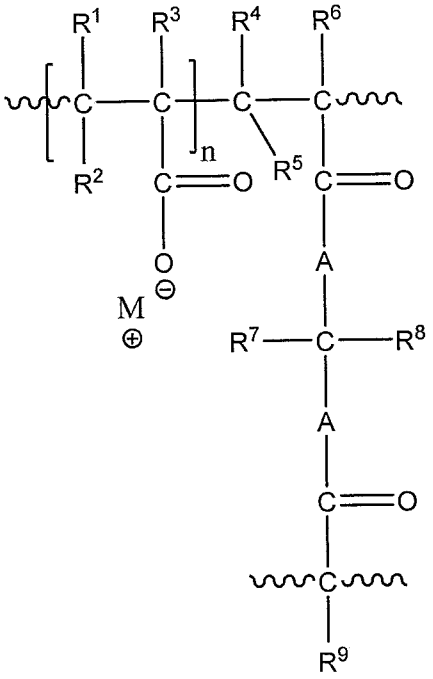
the wavy line (~~~) indicates the point of attachment to other repeating units of Formula (I).

In an aspect, there is provided an electrochemical cell comprising:

an anode structure comprising an element selected from the group consisting of group 1, group 2, group 8, group 12 and group 13 of the Periodic Table of Elements;

a cathode structure comprising a catalyst; and

a hydrogel located between the anode structure and the cathode structure, wherein the hydrogel comprises water and a cross-linked polymer having repeating units of the following formula (I):



(I)

wherein A is selected from the group consisting of –NH-, -C(O)O-, -OC(O)-, and -C(O)NR^{10}C(O)-;

R^1, R^2, R^3, R^4, R^5, R^6, R^7, R^8, R^9 and R^{10} are independently selected from the group consisting of hydrogen, optionally substituted alkyl, and optionally substituted alkenyl;

M is an alkali metal;

n is an integer of at least 1; and

the wavy line (~~~) indicates the point of attachment to other repeating units of Formula (I),

wherein the degree of cross-linking in the cross-linked polymer is in the range of 20 mol% to 80 mol%.

Advantageously, the cross-linked polymer in the hydrogel may be highly cross-linked (that is, it may have a number of repeating units in the range of about 50 to about 50,000 or a degree of cross-linking in the range of about 20 mol% to about 80 mol%. By being a highly cross-linked polymer, the hydrogel may be mechanically strong, having high tensile strength, elastic modulus, stress at break and strain at break measurement values, and may be able to be free-standing without the need to add additives or strengthening agents to the hydrogel. Hence, the hydrogel may optionally exclude the presence of mechanically strengthening agents such as glass fiber cloth.

In addition, due to the highly cross-linked nature of the polymer hydrogel, a greater number of M+O- can be absorbed by the cross-linked polymer, thus increasing the alkalinity of the hydrogel. Further, the cross-linked structure of the polymer may facilitate swelling of the polymer which in turn may allow for faster transport of OH- ions to facilitate battery reaction. Due to the cross-linked structure of the polymer in the hydrogel, it is to be noted that the polymer in the hydrogel does not have a linear structure.

The hydrogel further does not require further copolymerization or additional components in order to function as a polymer gel electrolyte. Further advantageously, the disclosed electrochemical cell may be used for traditional solid state Zn/air batteries and advanced solid-state bendable zinc/air batteries.

Advantageously, the disclosed electrochemical cells may be assembled into coin cell type Zn/air batteries. Further advantageously, these batteries may show superior discharge and cycling ability. Advantageously, the disclosed electrochemical cells may have high energy storage capacity.

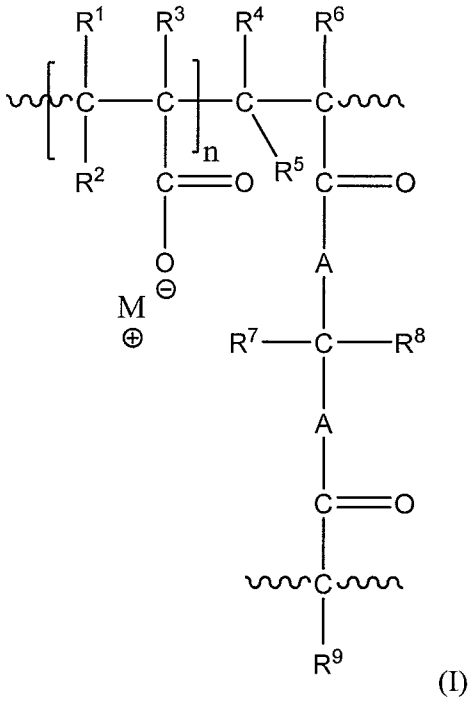
Advantageously, the hydrogel in the disclosed electrochemical cell is highly stable. This is in contrast to conventional hydrogels that are commonly known to collapse in the presence of high ionic strength which would not be suitable as the electrolyte of Zn/air batteries. Advantageously, the hydrogel in the disclosed electrochemical cell remains as a stable gel in the presence of high ionic strength and at high pH.

Further advantageously, the solid state nature of the electrochemical cell may circumvent the issues of conventional electronic cells which comprise a fluid aqueous electrolyte, thereby allowing the electrochemical cell to avoid or reduce problems such as displacement of the liquid electrolyte during operation. In addition, the solid state nature advantageously enables the electrochemical cell to have mechanical flexibility, therefore allowing the cells to be expandable/compressible. In addition, due to the sold-state nature of the electrochemical cell, the disclosed electrochemical cell can circumvent the issue of solvent evaporation from the liquid electrolyte.

Free standing alkaline polymer gel electrolyte films may be used to enable stable operation of Zn-AB cells of different forms, such as bendable all solid-state Zn-ABs, and compressible/expandable Zn-Abs.

There is provided a method for manufacturing an electrochemical cell, the method comprising the steps of:

providing a hydrogel comprising water and a cross-linked polymer having repeating units of the following formula (I):



(I)

wherein A is selected from the group consisting of –NH-, -C(O)O-, -OC(O)-, and -C(O)NR^{10}C(O)-;

R^1, R^2, R^3, R^4, R^5, R^6, R^7, R^8, R^9 and R^{10} are independently selected from the group consisting of hydrogen, optionally substituted alkyl, optionally substituted alkenyl and optionally substituted alkenyl;

M is an alkali metal;

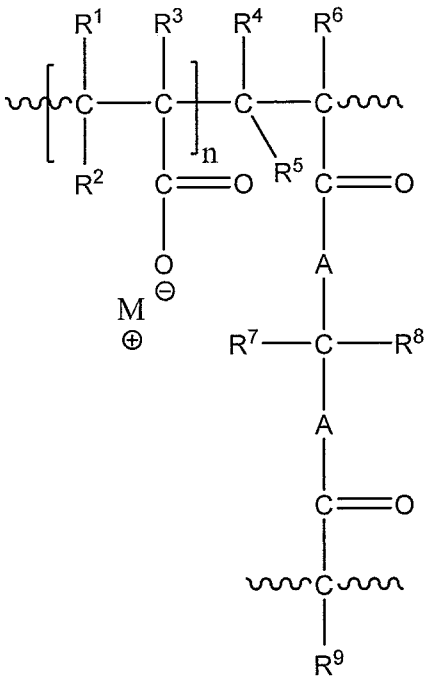
n is an integer of at least 1; and

the wavy line (~~~) indicates the point of attachment to other repeating units of Formula (I), and

contacting the hydrogel with an anode structure comprising an element selected from the group consisting of group 1, group 2, group 8, group 12 and group 13 of the Periodic Table of Elements; and a cathode structure comprising a catalyst; wherein the hydrogel is located between the anode structure and the cathode structure.

In another aspect, there is provided a method for manufacturing an electrochemical cell, the method comprising the steps of:

providing a hydrogel comprising water and a cross-linked polymer having repeating units of the following formula (I):



(I)

wherein A is selected from the group consisting of –NH-, -C(O)O-, -OC(O)-, and -C(O)NR^{10}C(O)-;

R^1, R^2, R^3, R^4, R^5, R^6, R^7, R^8,R^9 and R^{10} are independently selected from the group consisting of hydrogen, optionally substituted alkyl, and optionally substituted alkenyl;

M is an alkali metal;

n is an integer of at least 1; and

the wavy line (~~~) indicates the point of attachment to other repeating units of Formula (I),

wherein the degree of cross-linking in the cross-linked polymer is in the range of 20 mol% to 80 mol%, and

contacting the hydrogel with an anode structure comprising an element selected from the group consisting of group 1, group 2, group 8, group 12 and group 13 of the Periodic Table of Elements; and a cathode structure comprising a catalyst; wherein the hydrogel is located between the anode structure and the cathode structure.

In an embodiment, the providing step of the hydrogel may comprise the steps of:

irradiating a solution of an acrylic monomer, a cross-linking agent and a polymerization initiator to form a film; and

contacting said film with an aqueous solution comprising a base having a formula MOH

In a specific embodiment, the hydrogel may be formed by:

dissolving the acrylic monomer in water that is substantially free of dissolved gases, to form solution A;

dissolving a cross-linking agent and a polymerization initiator in water, to form solution B;

contacting solution A and solution B to form a mixture C;

pouring mixture C onto a surface to form a film;

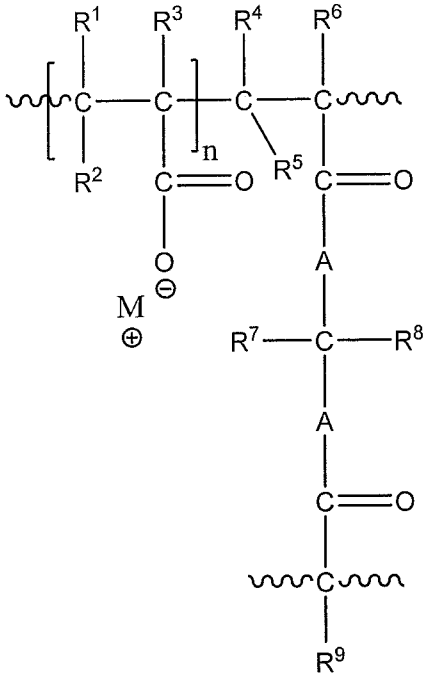
irradiating the film with ultraviolet radiation;

drying the film; and

contacting the dried film with an aqueous solution comprising a base having a formula MOH.

Advantageously, the method of manufacturing the electrochemical cell is straight forward and simple, and the method for providing the hydrogel only requires a single monomer. More advantageously, the components of the electrochemical cell may be easily assembled.

There is provided the use of a hydrogel comprising water and a cross-linked polymer having repeating units of the following formula (I) in a metal/air battery:



(I)

wherein A is selected from the group consisting of –NH-, -C(O)O-, -OC(O)-, and -C(O)NR^{10}C(O)-;

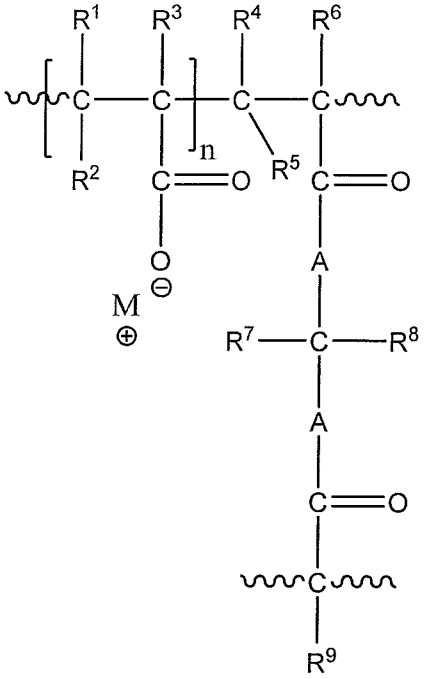
R^1, R^2, R^3, R^4, R^5, R^6, R^7, R^8,R^9 and R^{10} are independently selected from the group consisting of hydrogen, optionally substituted alkyl, optionally substituted alkenyl and optionally substituted alkenyl;

M is an alkali metal;

n is an integer of at least 1; and

the wavy line (~~~) indicates the point of attachment to other repeating units of Formula (I).

In another aspect, there is provided use of a hydrogel comprising water and a cross-linked polymer having repeating units of the following formula (I) in a metal/air battery:



(I)

wherein A is selected from the group consisting of –NH-, -C(O)O-, -OC(O)-, and -C(O)NR^{10}C(O)-;

R^1, R^2, R^3, R^4, R^5, R^6, R^7, R^8, R^9 and R^{10} are independently selected from the group consisting of hydrogen, optionally substituted alkyl, and optionally substituted alkenyl;

M is an alkali metal;

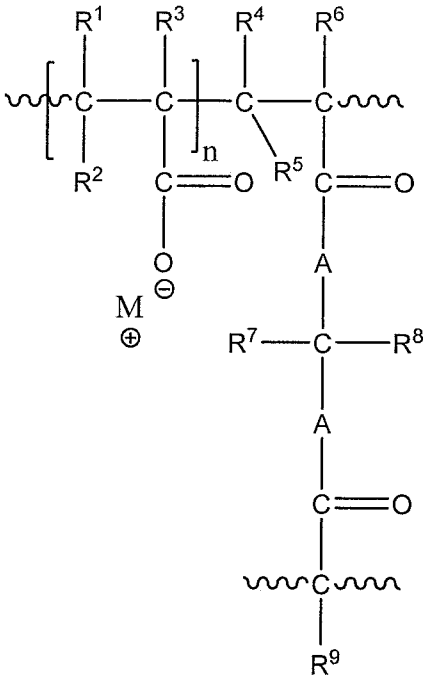
n is an integer of at least 1; and

the wavy line (~~~) indicates the point of attachment to other repeating units of Formula (I),

wherein the degree of cross-linking in the cross-linked polymer is in the range of 20 mol% to 80 mol%.

Advantageously, the hydrogel may be useful in Zn/air batteries that display superior discharge and cycling ability. In addition, the hydrogel may be useful in a bendable Zn/air batteries, as the hydrogel is not liquid, but solid-state, therefore avoiding issues with displacement of the liquid electrolyte in the electrochemical cell.

There is provided a method for synthesizing a hydrogel comprising water and a cross-linked polymer having repeating units of the following formula (I):



(I)

wherein A is selected from the group consisting of –NH-, -C(O)O-, -OC(O)-, and -C(O)NR^{10}C(O)-,

R^1, R^2, R^3, R^4, R^5, R^6, R^7, R^8, R^9 and R^{10} are independently selected from the group consisting of hydrogen, optionally substituted alkyl, optionally substituted alkenyl and optionally substituted alkenyl;

M is an alkali metal;

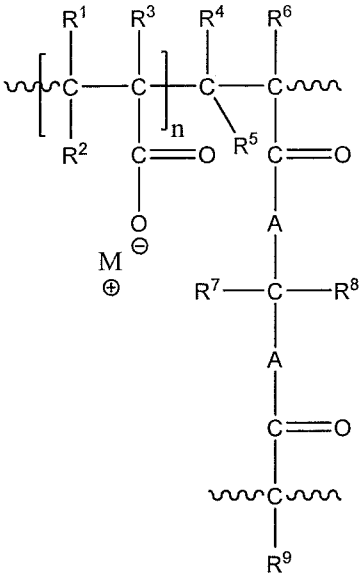
n is an integer of at least 1; and

the wavy line (~~~) indicates the point of attachment to other repeating units of Formula (I),

wherein the providing step comprises the steps of: irradiating a solution of an acrylic monomer, a cross-linking agent and a polymerization initiator to form a film; and

contacting said film with an aqueous solution comprising a base having a formula MOH.

In another aspect, there is provided a method for synthesizing a hydrogel comprising water and a cross-linked polymer having repeating units of the following formula (I):



(I)

wherein A is selected from the group consisting of –NH-, -C(O)O-, -OC(O)-, and -C(O)NR^{10}C(O)-,

R^1, R^2, R^3, R^4, R^5, R^6, R^7, R^8, R^9 and R^{10} are independently selected from the group consisting of hydrogen, optionally substituted alkyl, and optionally substituted alkenyl;

M is an alkali metal;

n is an integer of at least 1;

the wavy line (~~~) indicates the point of attachment to other repeating units of Formula (I); and

the degree of cross-linking in the cross-linked polymer is in the range of 20 mol% to 80 mol%,

wherein the providing step comprises the steps of: irradiating a solution of an acrylic monomer, a cross-linking agent and a polymerization initiator to form a film; and

contacting said film with an aqueous solution comprising a base having a formula MOH.

In another aspect, there is provided a hydrogel obtainable by the method as defined above.

Definitions

The following words and terms used herein shall have the meaning indicated:

"Current collector" for the purposes of this disclosure, refers to a material that receives electrons from generated by a catalyst, thereby providing a conducting path to the external circuit and minimising resistance of the electrochemical cell.